Diurnally Integrated Two- and Four-Stream Biases in SW Irradiances in Comparison to Monte Carlo Method

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Motivation

❑ Two- and four-stream approximations are used for irradiance calculations of CERES processing.

❑ The two- and four-stream biases are well understood for simplified cloud scenarios, but it is not clear how these biases will affect diurnally-integrated monthly or annual means of SW irradiances.

Objectives

1. Understand two- and four-stream biases for simplified cases

2. Integrate the two- and four-stream biases using CERES SYN surface, atmosphere, and cloud properties monthly and annually

3. Suggest long-term effects of the two- and four-stream biases in SW irradiance computations

Used Models and Methods

❑ Fu-Liou radiative transfer model modified by CERES team (FLCKKR) (Kratz and Rose 1999; Kato et al. 1999, 2005; Rose et al. 2006).

1) **Delta-two-stream-Eddington (2strEdd)** ————▶ **SYN Inhomogeneous clouds (GWTSA)**

(Irvine 1968; Kawata and Irvine 1970; Shettle and Weinman 1970)

$I(\mu, \tau) = I_0(\tau) + \mu I_1(\tau)$: The radiance is expressed by a polynomial of μ along with the zeroth (I_0) and first (I_1) Legendre polynomial moments of the radiance

2) **Delta-two-stream-quadrature (2strQuad)** (Liou 1992)

The angular integral of the radiance is expressed using the two-point gaussian quadrature

3) **Delta-four-stream-quadrature (4strQuad)** ————▶ **CCCM, Clear SYN, Homogeneous SYN clouds**

(Liou et al. 1988; Fu 1991)

The angular integral of the radiance is expressed using the four-point gaussian quadrature

❑ Reference Method: Intercomparison of 3-D Radiation Code (I3RC) (Cahalan et al. 2005) community **Monte Carlo model** (Pincus and Evans 2009) for plane parallel atmosphere
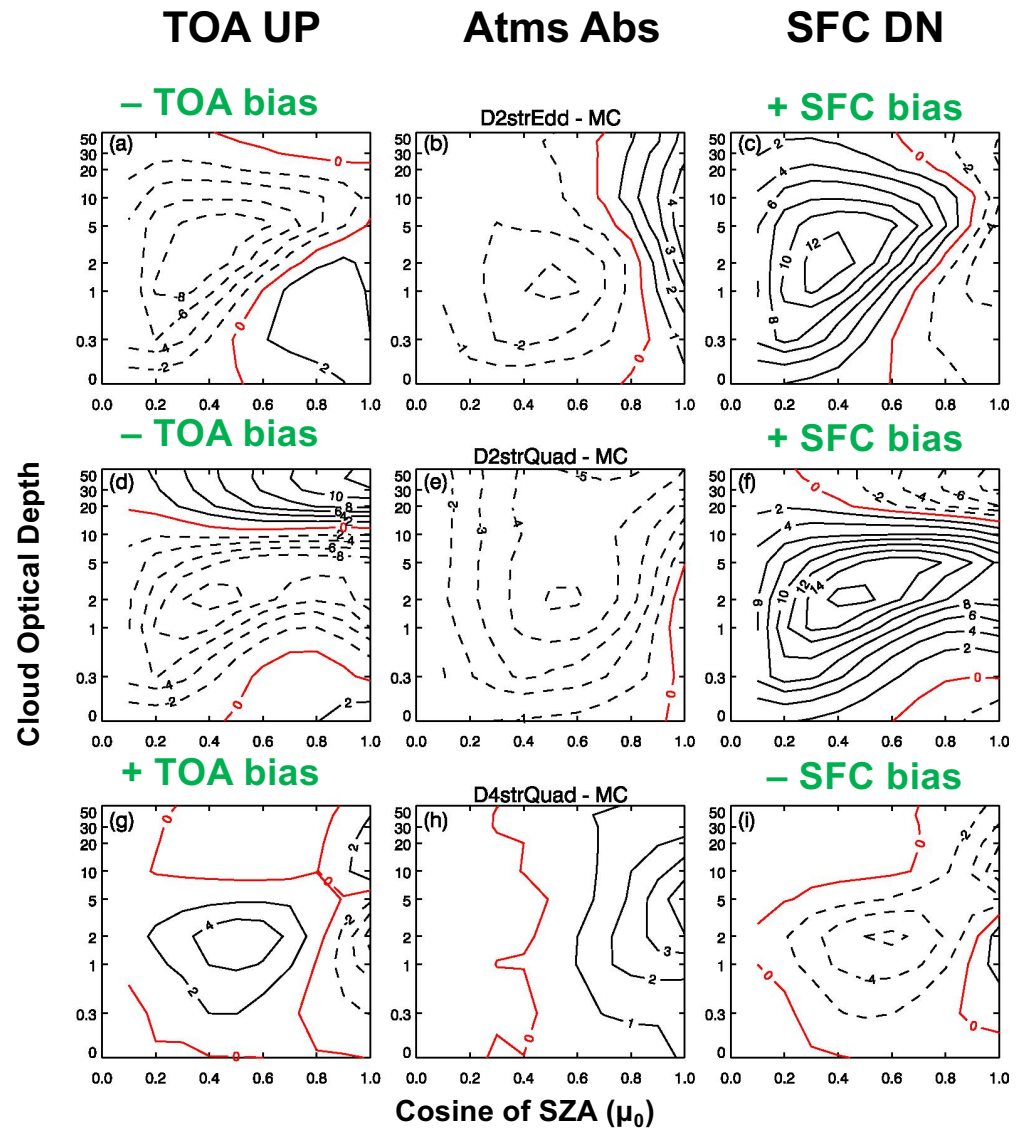
Simplified Case:
Water clouds (2-3 km) over ocean

- The two-stream methods gives negative biases at TOA and positive biases at surface.
- The four-stream method gives better results than the two-stream methods.
- Biases in absorbed flux are smaller than those at TOA or surface.

TOA UP **Atms Abs** **SFC DN**

2strEdd – MC

2strQuad – MC

4strQuad – MC

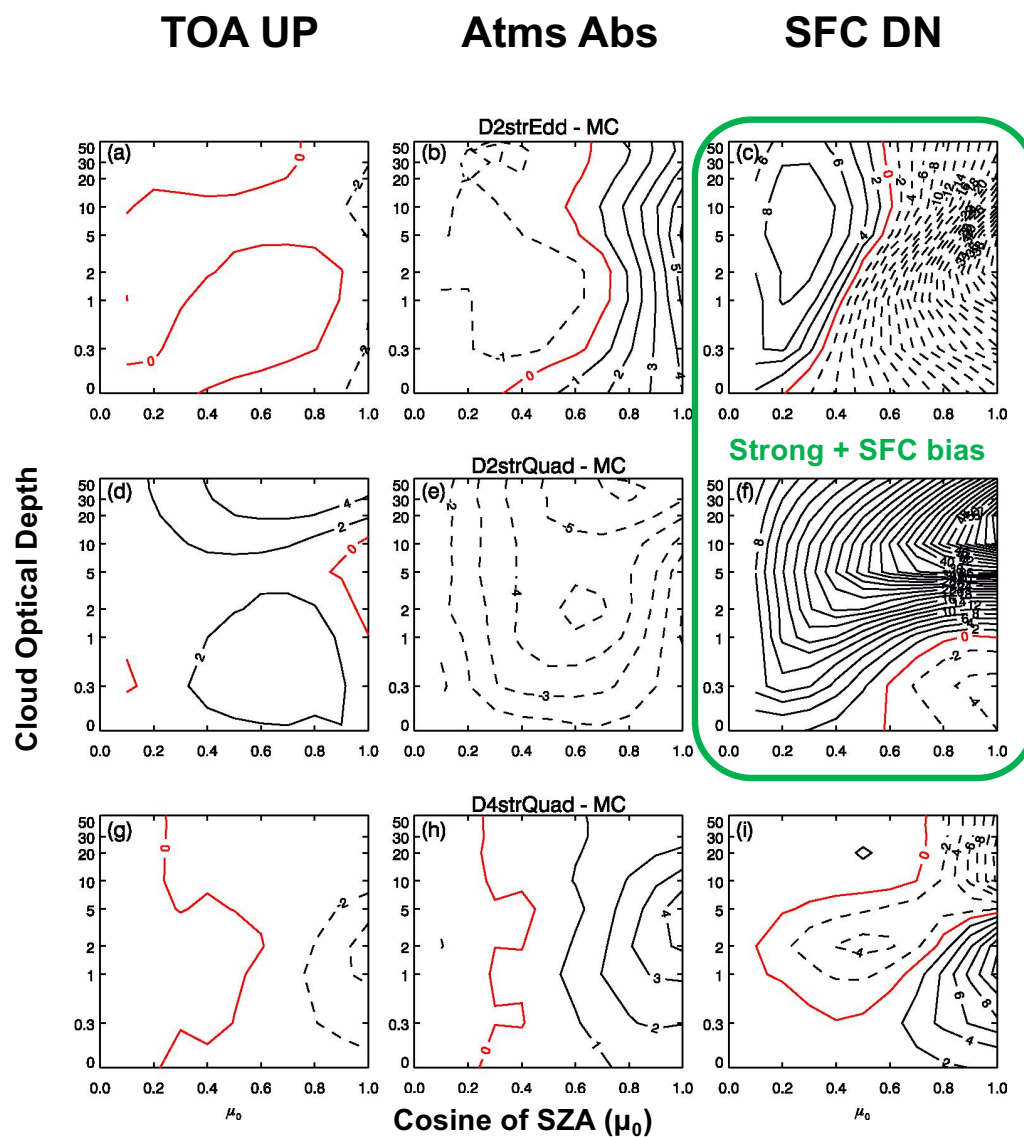Cloud Optical Depth

Cosine of SZA (μ_0)

Large Two-stream Biases over Snow (Water Clouds 2-3 km)

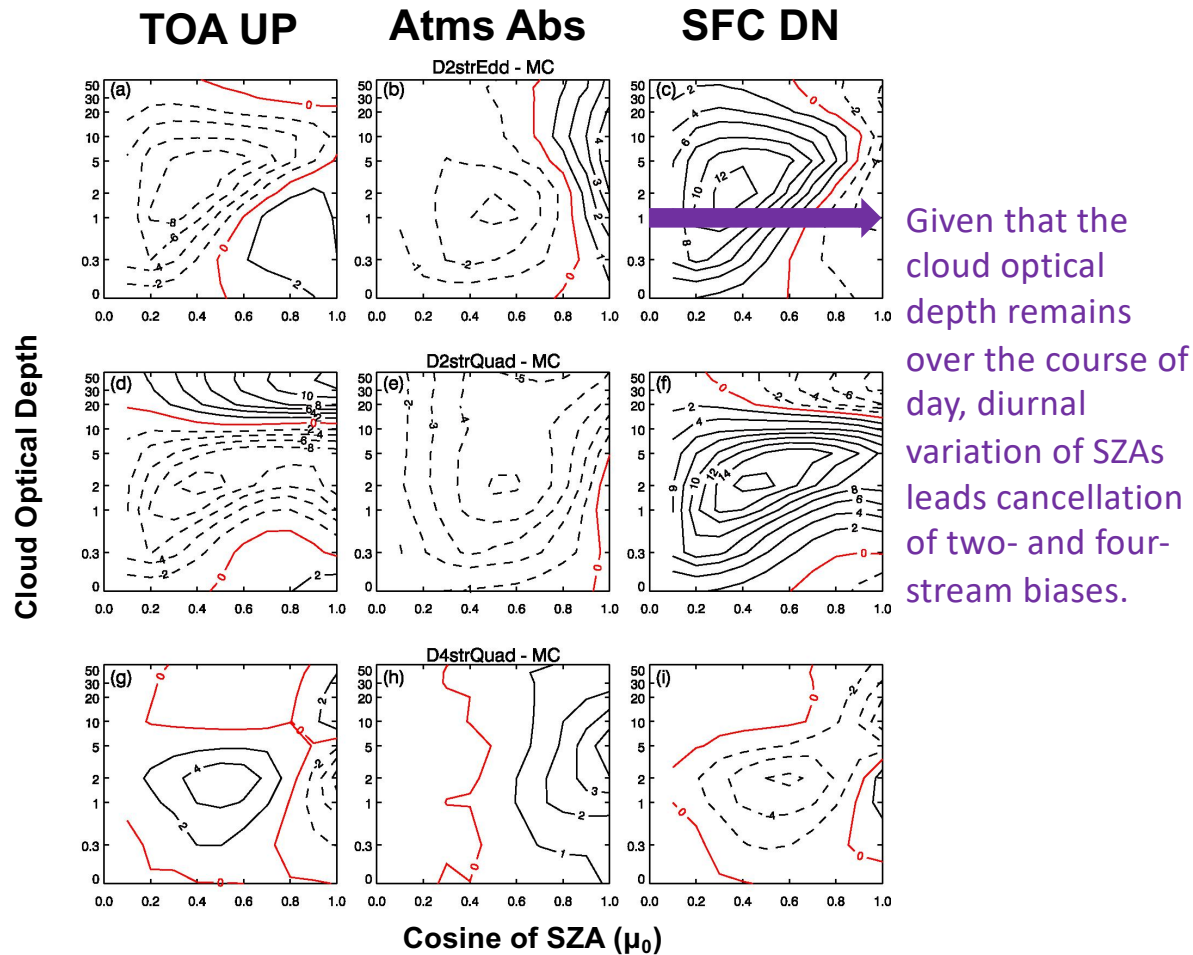o The two-stream methods gives large biases at surface downward irradiances over snow surface type.

TOA UP **Atms Abs** **SFC DN**

2strEdd – MC

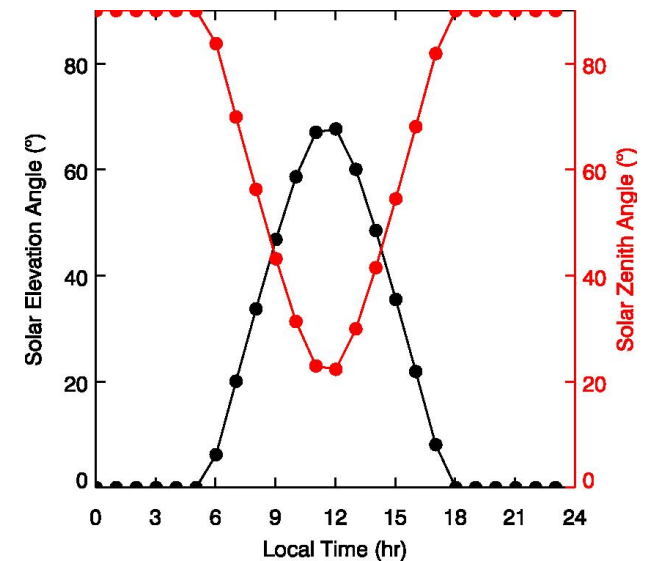**2strQuad – MC**

4strQuad – MC

Strong + SFC bias

5

Impact of Diurnal Integration:

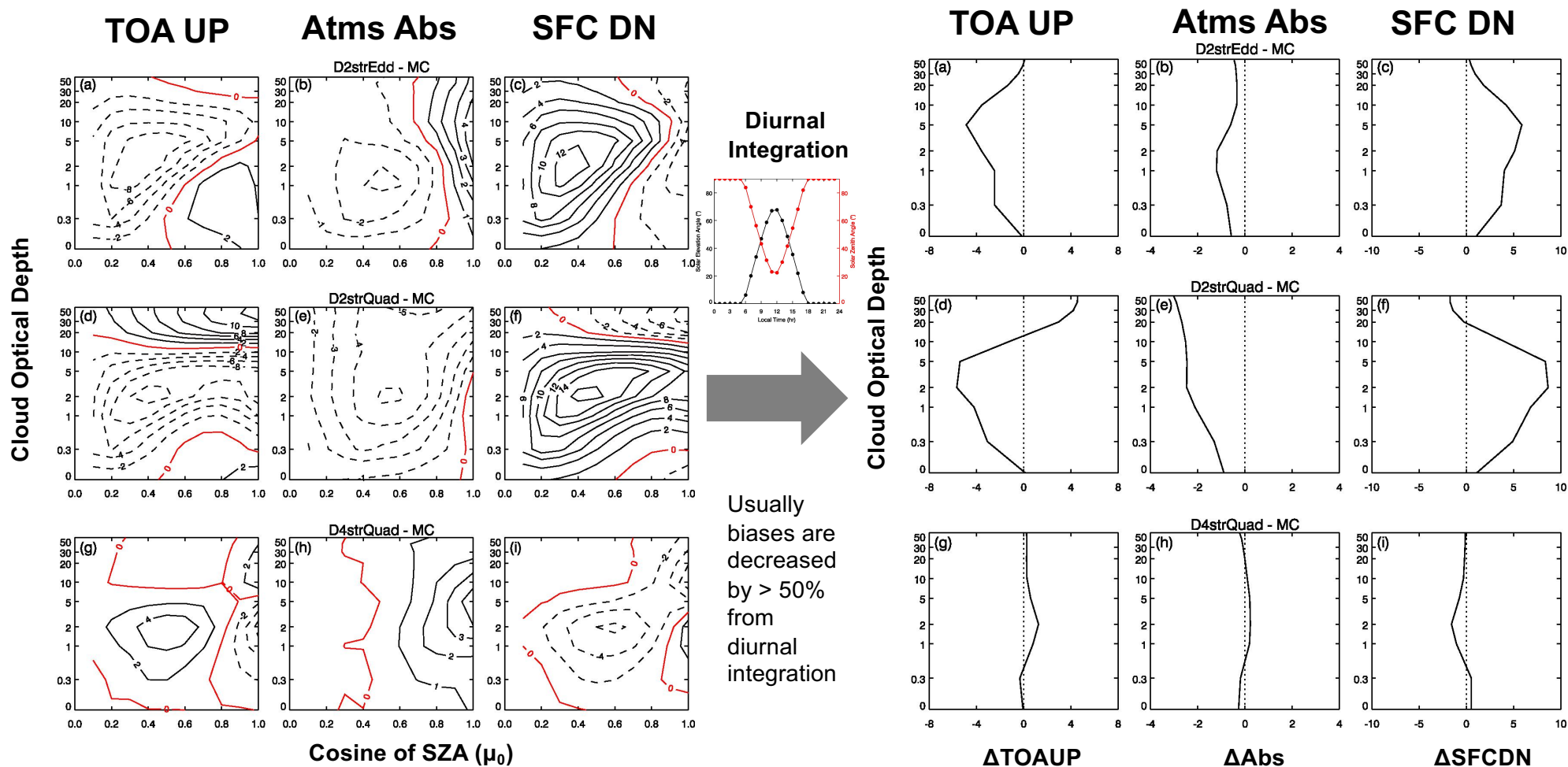For the same cloud optical depth, diurnal variation of SZAs leads cancellation of two- and four-stream biases.

Given that the cloud optical depth remains over the course of day, diurnal variation of SZAs leads cancellation of two- and four-stream biases.

Impact of Diurnal Integration:

Diurnally integrated two- and four-stream biases are smaller than hourly biases.

TOA UP   **Atms Abs**   **SFC DN**

Diurnal Integration

Usually biases are decreased by > 50% from diurnal integration

Cloud Optical Depth

Cosine of SZA (μ_0)

TOA UP   **Atms Abs**   **SFC DN**

D2strEdd – MC

D2strQuad – MC

D4strQuad – MC

Cloud Optical Depth

ΔTOAUP   ΔAbs   ΔSFCDN

Two- and Four-stream biases for SW heating rates (Water Clouds at 2-3km, Tau=10)

o Both two-stream methods (2strEdd and 2strQuad) produce negative biases at the altitude of cloud layers, and positive biases below the cloud layers.

o The four-stream method (4strQaud) produces close agreement with MC results.

o The sign of biases remain the same for different SZAs for two stream methods **(less cancellation in diurnal integration)**, but not four-stream method **(more cancellation)**.

ΔHR (K d^{-1}) (Red, blue, and green lines)

Reference HR (K d^{-1}) (Black lines)
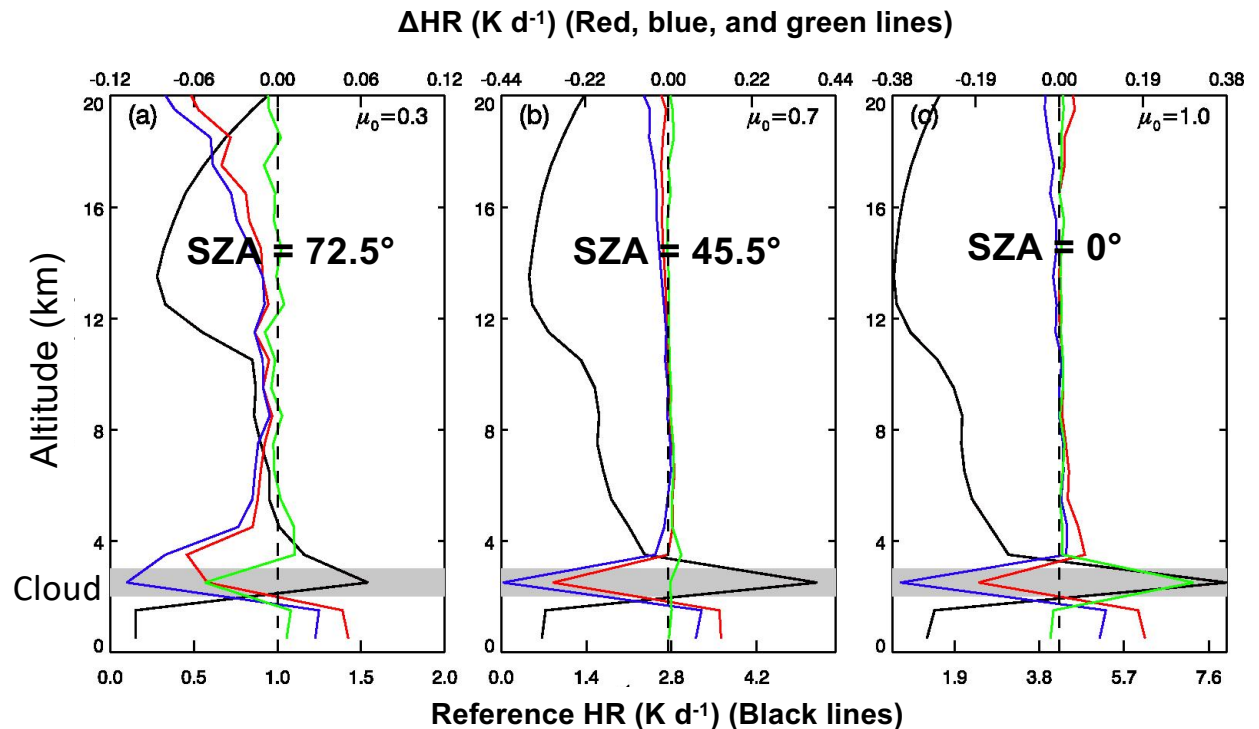
Monte Carlo (MC): Reference
2strEdd – MC
2strQuad – MC
4strQuad – MC

Model Inputs – CERES Ed4 SYN hourly Product

❑ Surface: CERES SYN ocean and snow/ice coverages

    o   Snow albedo model (Jin et al., 2004) when snow/ice coverage > 10%

    o   Ocean albedo model (Jin et al., 2004) when the ocean coverage $\geqq$ 50% and snow/ice coverage $\leqq$ 10%

    o   Land surface albedo 0.1 for clear sky, and 0.12 for cloudy sky when ocean coverage is < 50% and snow/ice coverage $\leqq$ 10%

❑ Clouds: CERES SYN cloud properties for up four cloud types – low(> 700 hPa), mid-low (500-700 hPa), mid-high (300-500 hPa), and high (< 300 hPa)

    o   Cloud phase: liquid or ice

    o   Cloud top & base heights: truncated at a 1-km resolution

    o   Cloud optical depth: truncated at 51 cloud optical depth bins

❑ Temperature and WV profiles: CERES precipitable water (PW)

    o   Midlatitude summer (MLS) standard profile when PW > 1 cm

    o   Midlatitude winter (MLW) standard profile when PW $\leqq$ 1 cm

→ Radiative computations are performed up to five scenarios (clear, low, mid-low, mid-high, and high) for each hourly grid box, and these are averaged based on cloud areas. Then fluxes at hourly grid boxes are monthly and annually averaged.
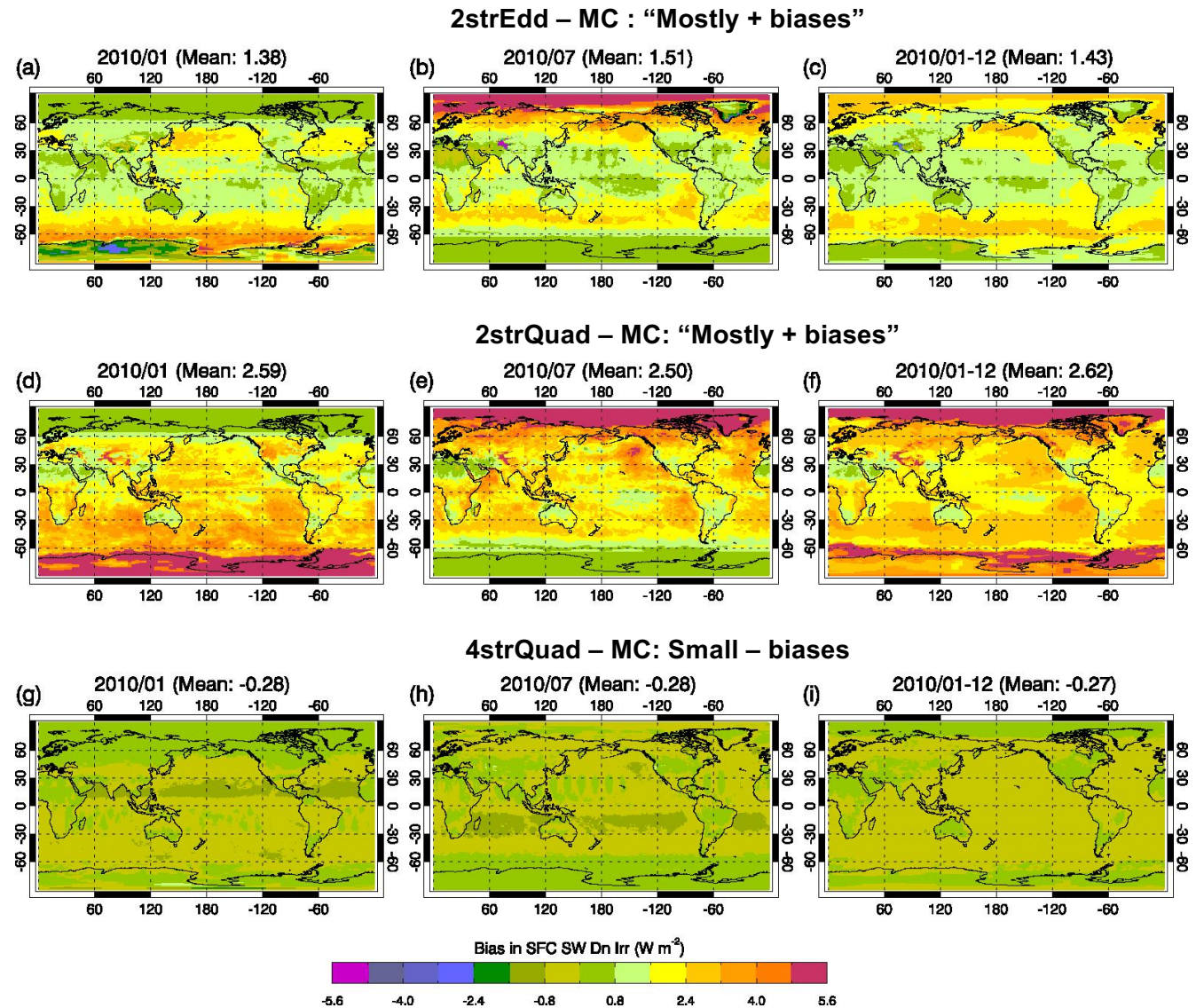
Integrated Two- and Four-stream biases in TOA SW Upward Irradiances

- The large negative two-stream biases appear in cloudy regions.
- Annual and monthly global means of biases are very similar, suggesting that the biases are not cancelled for long-term means.
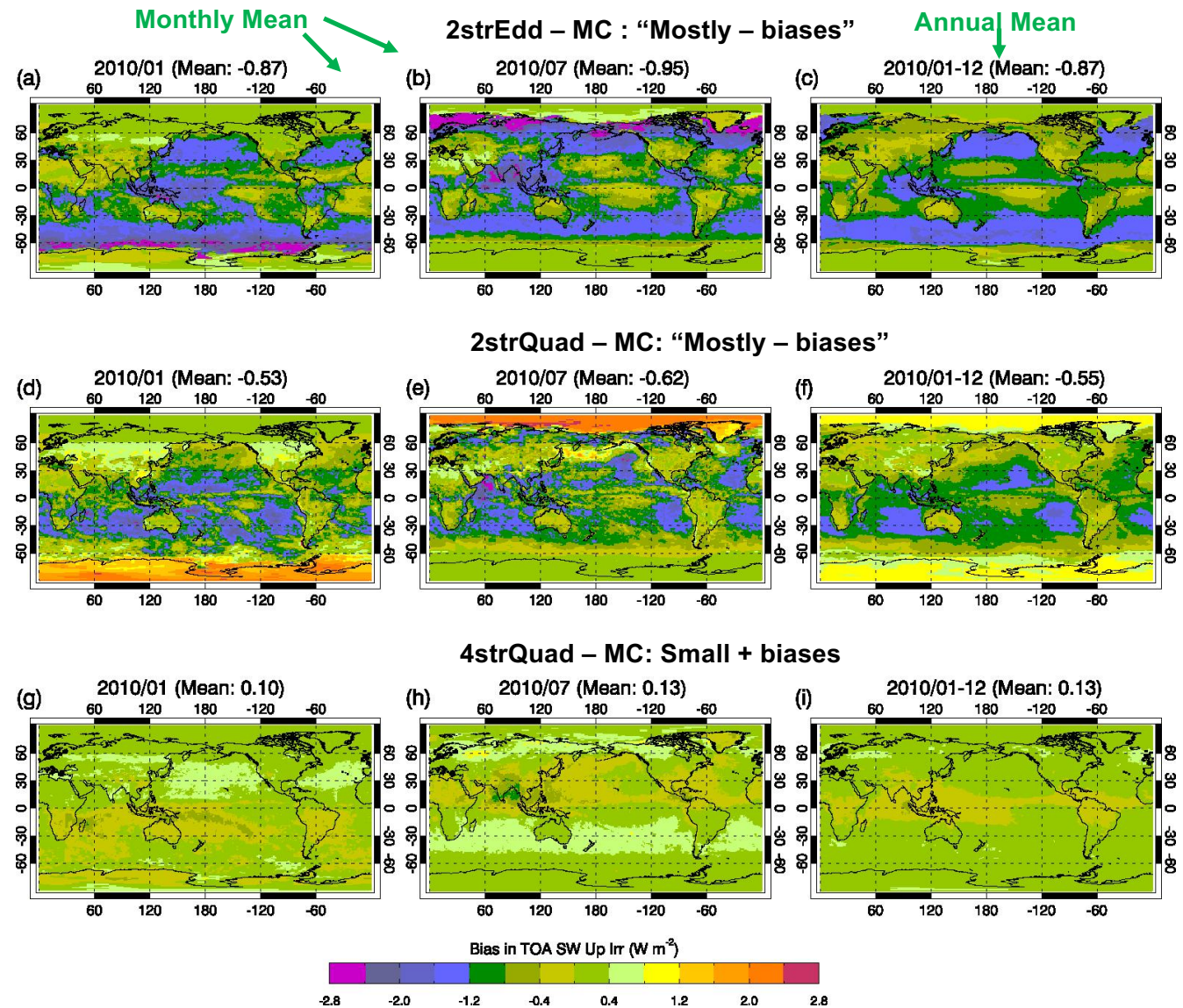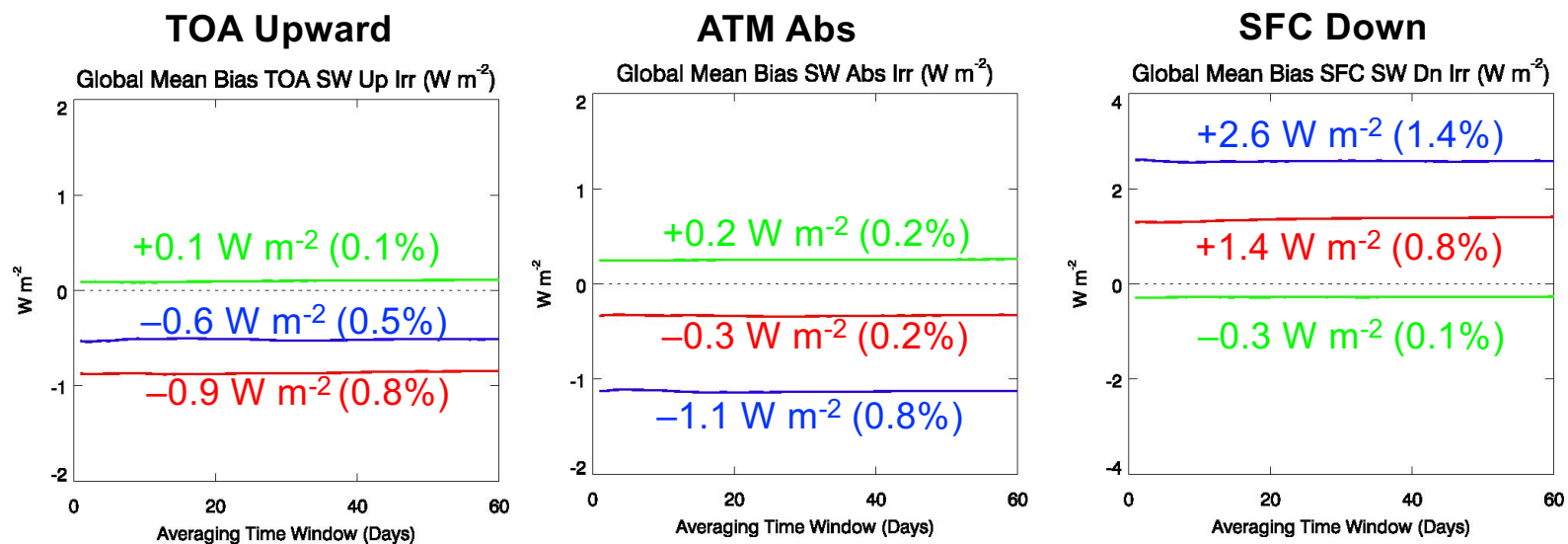
Integrated Two- and Four-stream biases in SW SFC Dn Irradiances

- The large positive two-stream biases appear in cloudy region.
- Annual and monthly global means are very similar, suggesting that the biases are not cancelled for long-term means.

2strEdd – MC : "Mostly + biases"

(a) 2010/01 (Mean: 1.38) (b) 2010/07 (Mean: 1.51) (c) 2010/01-12 (Mean: 1.43)

2strQuad – MC: "Mostly + biases"

(d) 2010/01 (Mean: 2.59) (e) 2010/07 (Mean: 2.50) (f) 2010/01-12 (Mean: 2.62)

4strQuad – MC: Small – biases

(g) 2010/01 (Mean: -0.28) (h) 2010/07 (Mean: -0.28) (i) 2010/01-12 (Mean: -0.27)

Bias in SFC SW Dn Irr (W m^{-2})

-5.6   -4.0   -2.4   -0.8   0.8   2.4   4.0   5.6

Global Mean and RMS Biases depending on Averaging Time Window
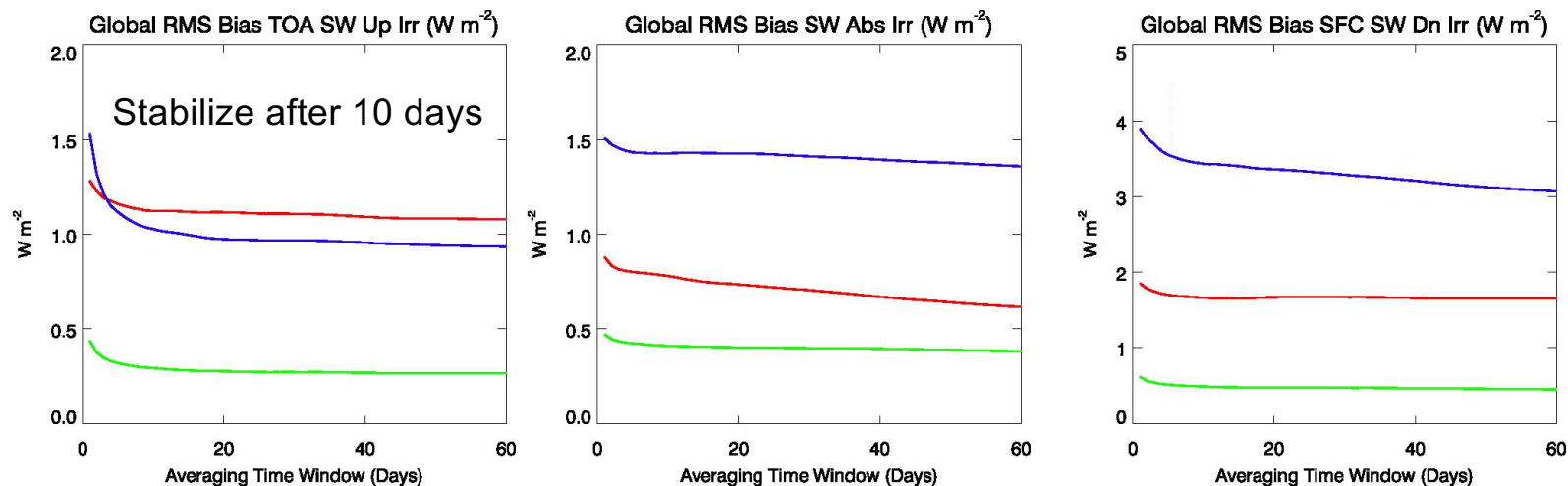
Integrated Two- and Four-stream biases in SW Heating Rates

o 2strEdd produces negative biases at cloud layers, and positive biases below cloud layers.

o 2strQuad produces larger negative biases than 2strEdd method.

o 4strQuad method produces negligible biases in computed heating rates.

2strEdd – MC : – HR bias at clouds,+ bias below clouds

2strQuad – MC : – HR bias at clouds

4strQuad – MC
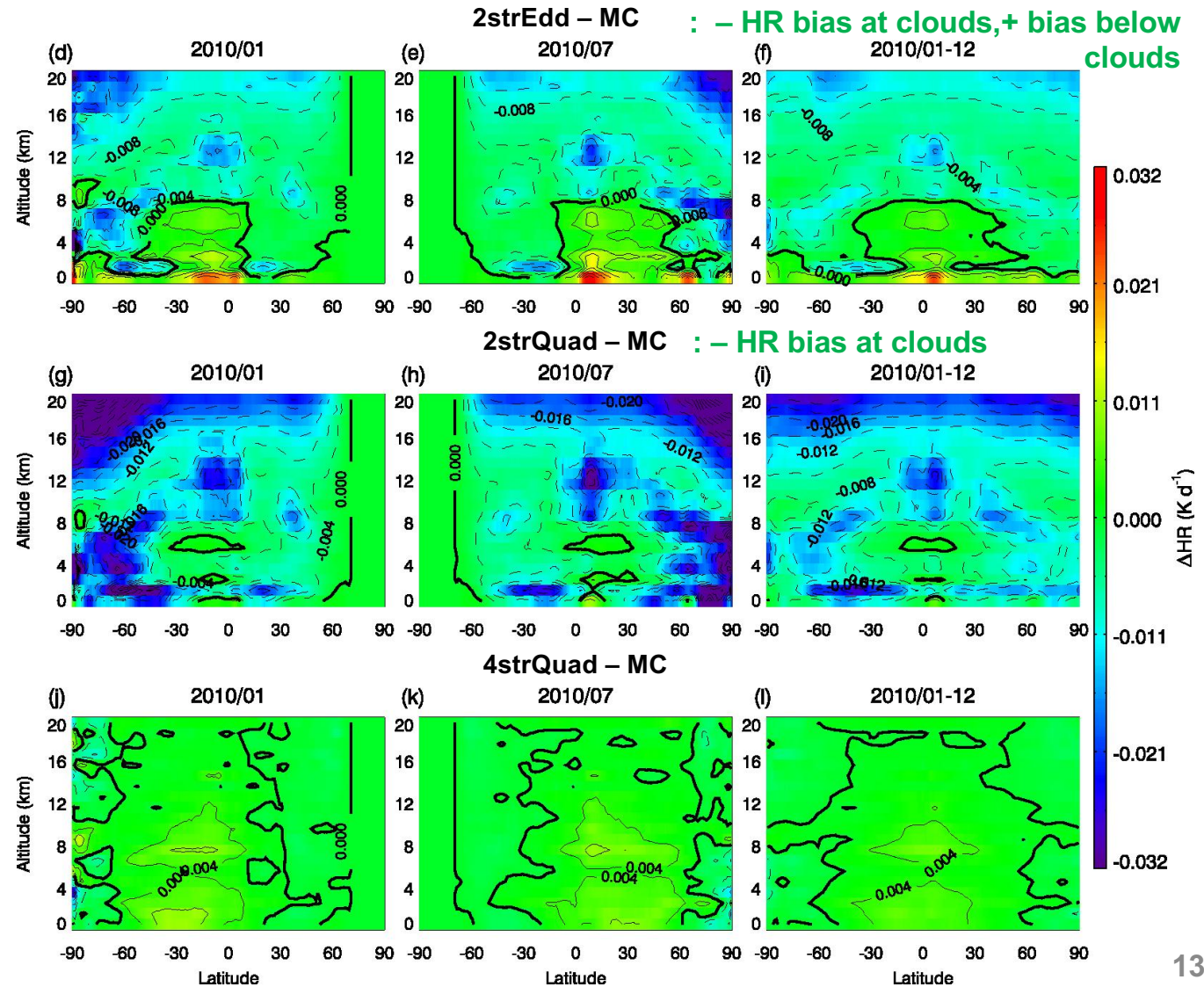
Conclusions

o When integrating biases diurnally, positive and negative signs are compensating and the magnitude gets smaller by more than 50%. The biases are further smoothed when considering various cloud optical depths using CERES SYN product. However, monthly and annual global means are very close, and RMS biases stabilize once the averaging time window > 10 days. The global mean two-stream biases can be order of 0.5–1 W m^{-2} at TOA and 1.5–2.5 W m^{-2} at surface in the long-term means (corresponding < 1.5%).

o Delta-four-stream-quadrature (4strQuad) method shows much smaller biases (< 0.2%) than two-stream methods.

o Compared to 2strQuad, 2strEdd method generally shows a better performance (e.g. snow surface, and HR profiles).

Thank you for your attention!

Simplified Case:
Ice clouds (10–12 km) over ocean

o Overall signs and
  magnitudes are
  very similar to the
  water cloud case.

o Slight differences
  from water cloud
  cases are due to
  different scattering
  phase functions (or
  simply asymmetry
  parameter).
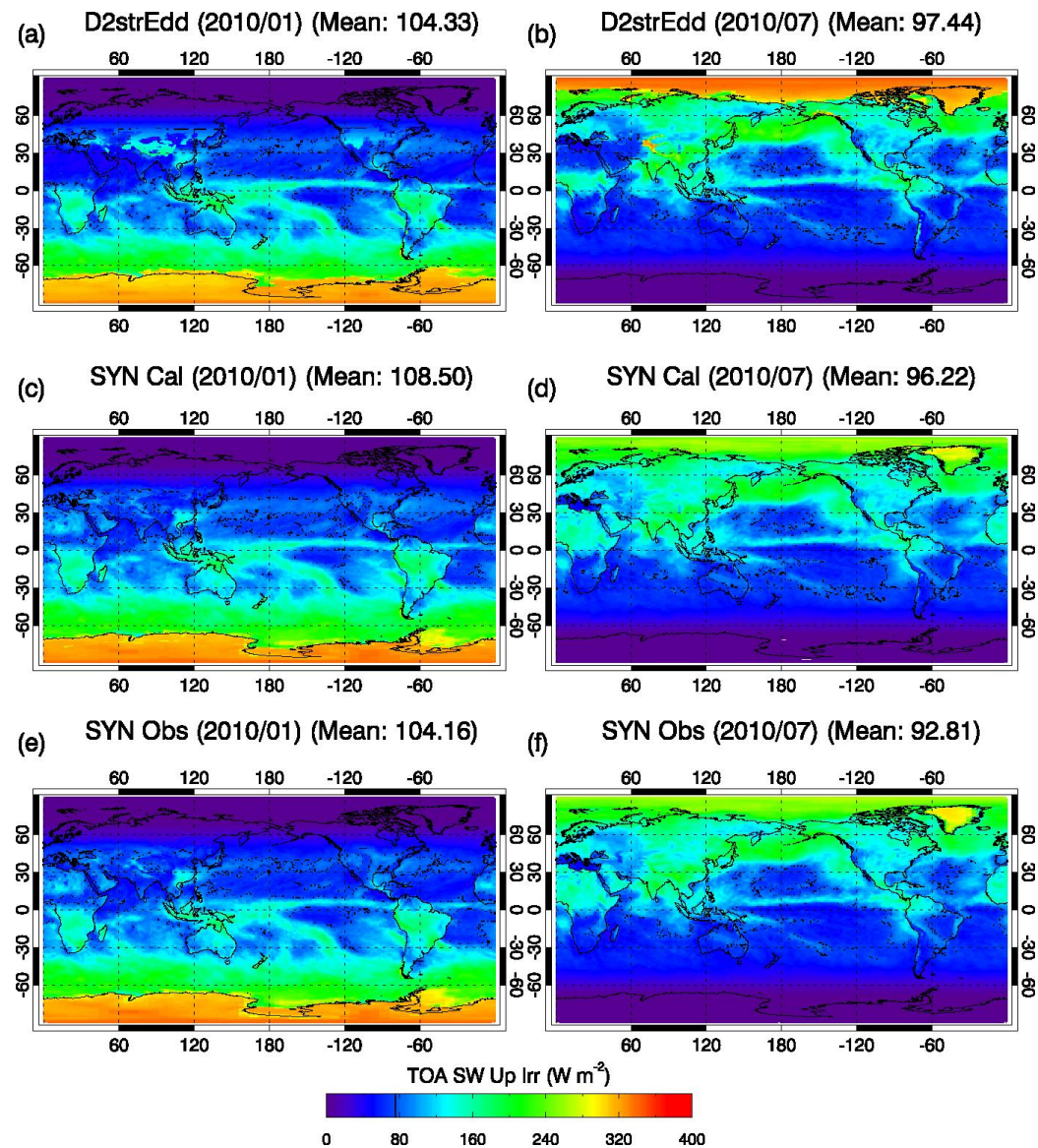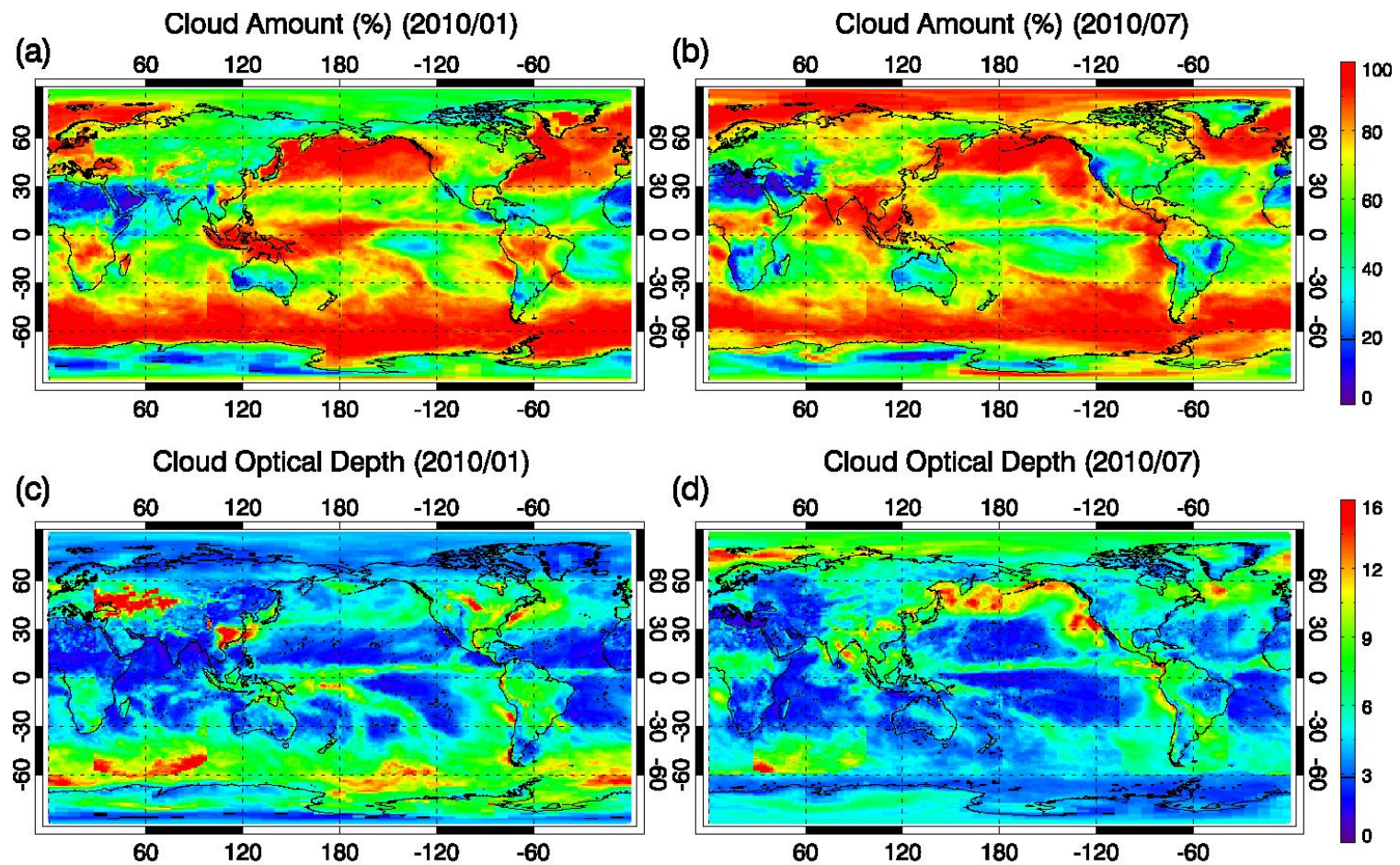

TOA UP   Atms Abs   SFC DN

2strEdd – MC

2strQuad – MC

4strQuad – MC

Cloud Optical Depth

Cosine of SZA (μ_0)

16
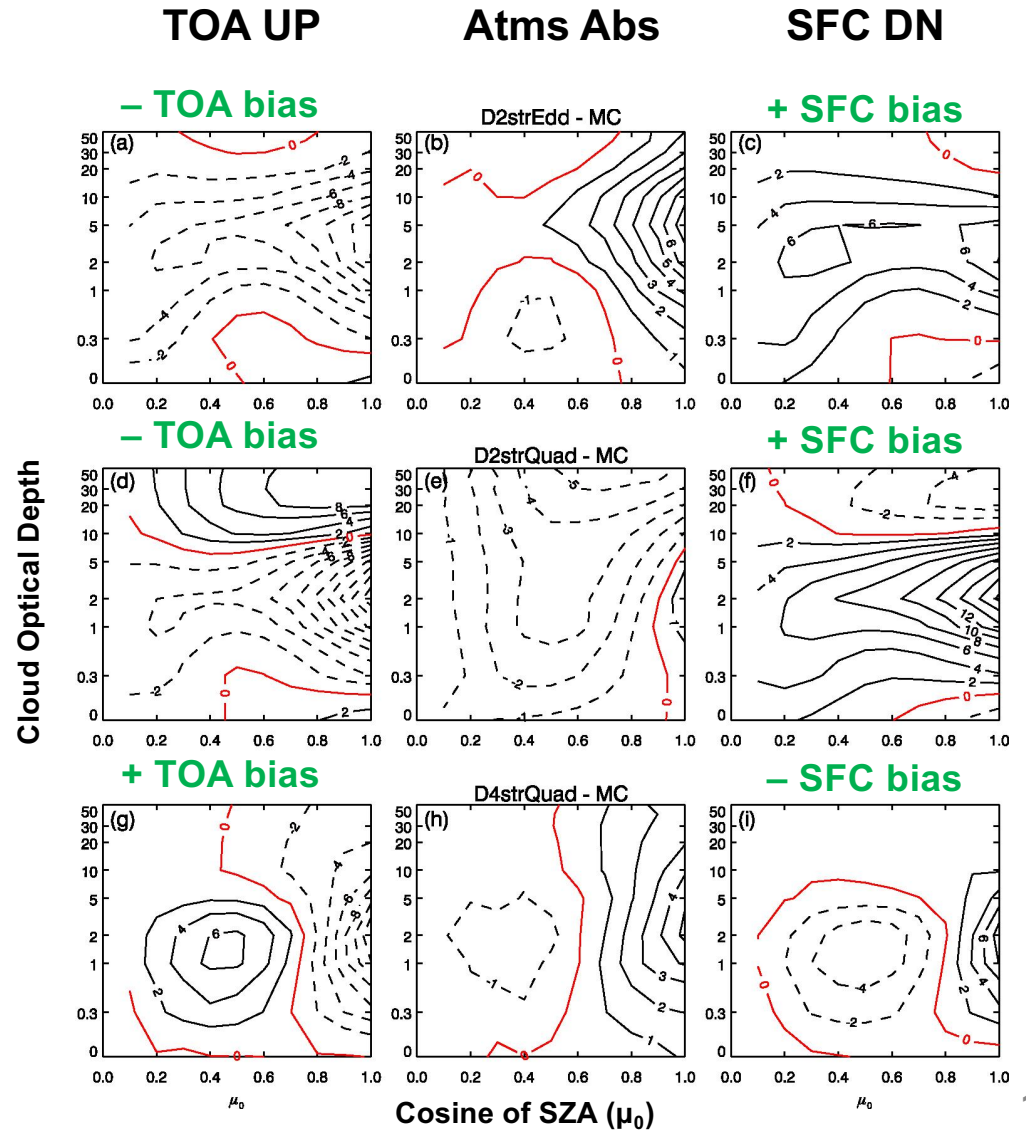
Summary of Annual SW Biases Due to Two- and Four-Stream Approximations (Annual Mean)

	Domain				
	Global	Ocean	Land	Antarctic	Arctic
Method	90°S–90°N	60°S–60°N	60°S–60°N	90°S–60°S	60°N–90°N
	TOA upward Irradiances (W m^{-2})				
MC	101.19	97.08	103.83	109.68	122.57
2strEdd	100.33	96.00	103.29	109.18	122.32
	(−0.87)	(−1.09)	(−0.54)	(−0.50)	(−0.25)
2strQuad	100.64	96.20	103.62	109.92	123.17
	(−0.55)	(−0.88)	(−0.21)	(−0.24)	(−0.60)
4strQuad	101.32	97.21	103.90	109.95	122.77
	(+0.13)	(+0.13)	(+0.07)	(+0.28)	(+0.19)
	Surface Downward Irradiances (W m^{-2})				
MC	187.31	196.08	211.63	104.88	104.68
2strEdd	188.74	197.66	212.56	106.64	106.02
	(+1.43)	(+1.58)	(+0.93)	(+1.76)	(+1.34)
2strQuad	189.93	198.52	213.83	108.88	109.03
	(+2.62)	(+2.45)	(+2.20)	(+4.00)	(+4.35)
4strQuad	187.04	195.65	211.63	104.86	104.68
	(−0.27)	(−0.43)	(−0.00)	(−0.02)	(0.00)

(a) D2strEdd (2010/01) (Mean: 104.33)   (b) D2strEdd (2010/07) (Mean: 97.44)

(c) SYN Cal (2010/01) (Mean: 108.50)   (d) SYN Cal (2010/07) (Mean: 96.22)

(e) SYN Obs (2010/01) (Mean: 104.16)   (f) SYN Obs (2010/07) (Mean: 92.81)

TOA SW Up Irr (W m^{-2})

0   80   160   240   320   400

CERES SYN Ed4 Cloud Properties

Cloud Amount (%) (2010/01)

Cloud Amount (%) (2010/07)

Cloud Optical Depth (2010/01)

Cloud Optical Depth (2010/07)

CERES SYN Ed4 Surface and Atmospheric Properties
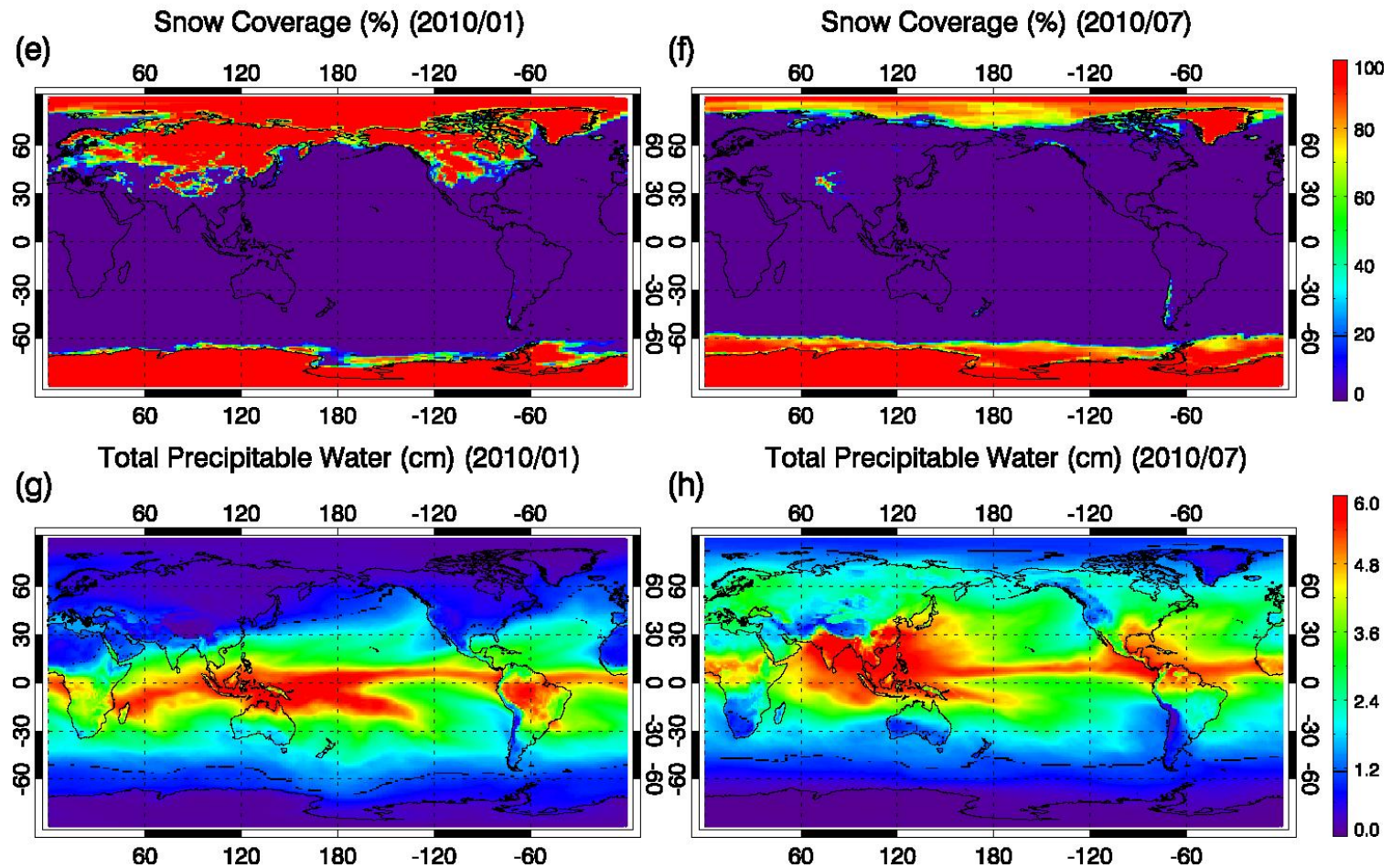
Radiative Transfer Method (Meador and Weaver, 1980)

TABLE 1. Coefficients γ_i in the two-stream equations (12) and (13).

Method	γ_1	γ_2	γ_3
Eddington	$\frac{1}{4}[7 - \omega_0(4 + 3g)]$	$-\frac{1}{4}[1 - \omega_0(4 - 3g)]$	$\frac{1}{4}(2 - 3g\mu_0)$
Modified Eddington	$\frac{1}{4}[7 - \omega_0(4 + 3g)]$	$-\frac{1}{4}[1 - \omega_0(4 - 3g)]$	β_0
Quadrature	$(3^{1/2}/2)[2 - \omega_0(1 + g)]$	$(3^{1/2}\omega_0/2)(1 - g)$	$\frac{1}{2}(1 - 3^{1/2}g\mu_0)$
Modified quadrature*	$3^{1/2}[1 - \omega_0(1 - \beta_1)]$	$3^{1/2}\omega_0\beta_1$	β_0
Hemispheric constant	$2[1 - \omega_0(1 - \beta)]$	$2\omega_0\beta$	β_0
Delta function	$\mu_0^{-1}[1 - \omega_0(1 - \beta_0)]$	$\omega_0\beta_0/\mu_0$	β_0
Hybrid modified Eddington-delta function	$\dfrac{7 - 3g^2 - \omega_0(4 + 3g) + \omega_0 g^2(4\beta_0 + 3g)}{4[1 - g^2(1 - \mu_0)]}$	$-\dfrac{1 - g^2 - \omega_0(4 - 3g) - \omega_0 g^2(4\beta_0 + 3g - 4)}{4[1 - g^2(1 - \mu_0)]}$	β_0

* β_1 corresponds to $\mu_1 = 3^{-1/2}$.

Monte Carlo Noise → Seems to be negligible
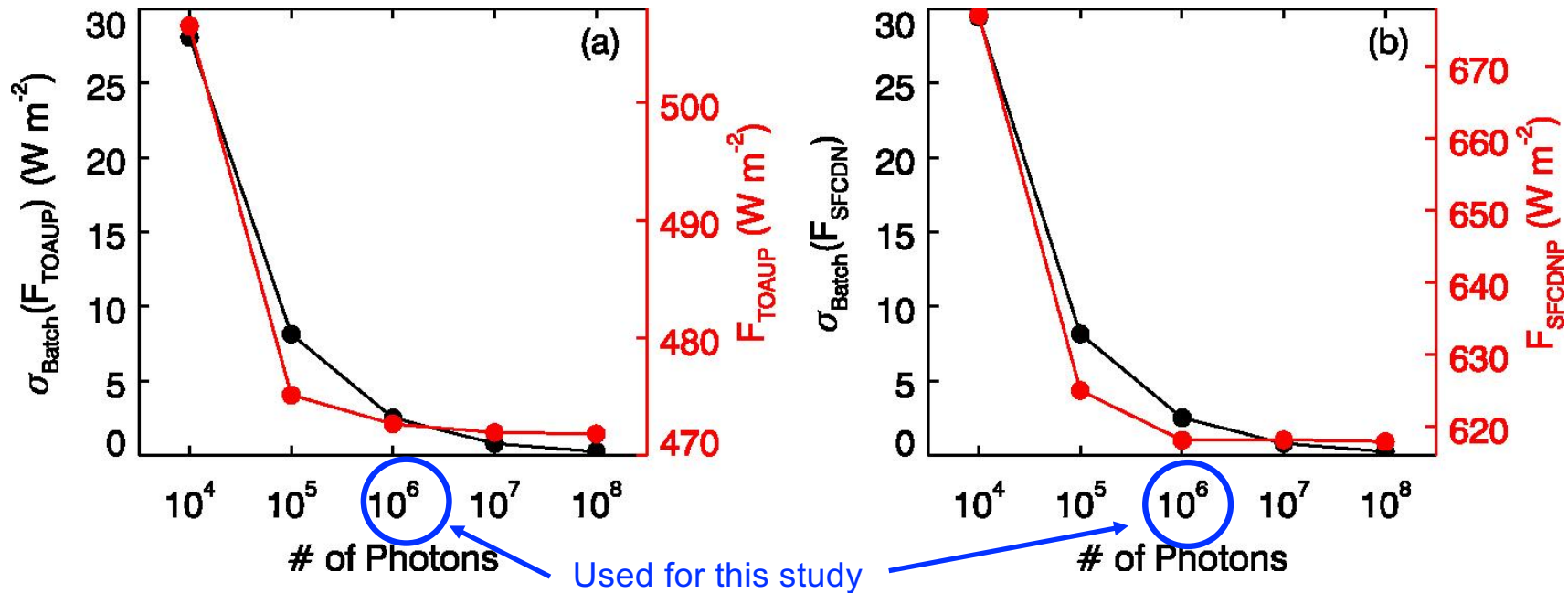
- A standard deviation of computed irradiances is computed among 100 batches, which can be considered as a Monte Carlo noise.
- The noise decreases with the number of photons, largely decreases at $10^4 \to 10^6$ photons.
- Once the number of photons exceeds 10^6 photons, the results get reliable, showing < 0.6 W m^{-2}.